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INITIAL PENETRATION OF PROJECTILES INTO CONCRETE AND PLASTER OF PARIS

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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INITIAL PENETRATION OF PROJECTILES INTO CONCRETE AND PLASTER OF PARIS

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ABSTRACT: The forces felt by a projectile were measured during its initial penetration of concrete and plaster of paris. Various nose shapes were tested. The testing technique used was that of firing concrete and plaster of paris at small-scale stationary models instrumented with SR-4 electrical resistance type strain gages on the afterbody.

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This report is the result of a program conducted to gather necessary data for the design of ground penetrating projectiles.

The research was supported by the Advanced Research Projects Agency, U. S. Army Supply and Maintenance Command under Contract No. 97X0400.1304 Research, Development, Test and Evaluation, Defense Agencies.

It must be acknowledged that the original idea of testing models in the manner described herein was that of Dr. A. E. Seigel. Valuable contributions related to testing techniques and data reduction were made by Dr. V. C. D. Dawson. Appreciation is expressed to the National Sand and Gravel Association for making the use of their laboratory at the University of Maryland available, and for providing advice and the services of their technicians to aid in the manufacture of the concrete target projectiles.

E. F. SCHREITER
Captain, USN
Commander

A. E. SEIGEL
By direction

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INTRODUCTION

The purpose of this work was to determine, for design purposes, the forces experienced by a projectile during its initial penetration into earth and concrete-like materials. In this study, concrete mortar and plaster of paris were used as the impacted material. Projectile nose shapes tested were hemispherical, ogival and conical. The angle of impact was 90 degrees.

BACKGROUND

Presently there is a limited amount of data available for the design of missiles which must penetrate soils, rock, and concrete. For purposes of definition, this penetration may be divided into two phases: (1) initial entry, and (2) subterranean travel. The present study was limited to the initial entry phase which is considered complete when the missile nose has fully entered the impacted medium. The data needed for missile design for this phase are a pressure-time history for the missile nose or a time history of a directly related quantity such as strain, force, or acceleration. These data should ideally be obtained from a transducer with a high frequency response capable of giving the desired time history directly.

APPROACH

Because of the difficulties involved in recording data from an instrumented flying model, the model used was stationary and the impacted material, in this case concrete or plaster of paris, was fired at it.

TEST FACILITY

The test facility consists of a 4-inch gun which fires the impacting material at a missile model mounted in an evacuated chamber. Figure 1 is a schematic diagram of the facility. The gun barrel has a bore of 4 inches and a length of 60 feet; the gun chamber is 10 inches in diameter and 12 feet long. Operated as an air gun with 3,000 psi house air, velocities up to 2,750 feet per second are attained. The gun can be operated using gunpowder for higher velocities, the limiting factor in this case being the strength of the concrete or plaster of paris impacting material.

The muzzle of the gun protrudes into the target chamber, and both chamber and barrel are evacuated to a pressure of 3 mm Hg or less. This procedure eliminates air shock and minimizes gun blast problems.

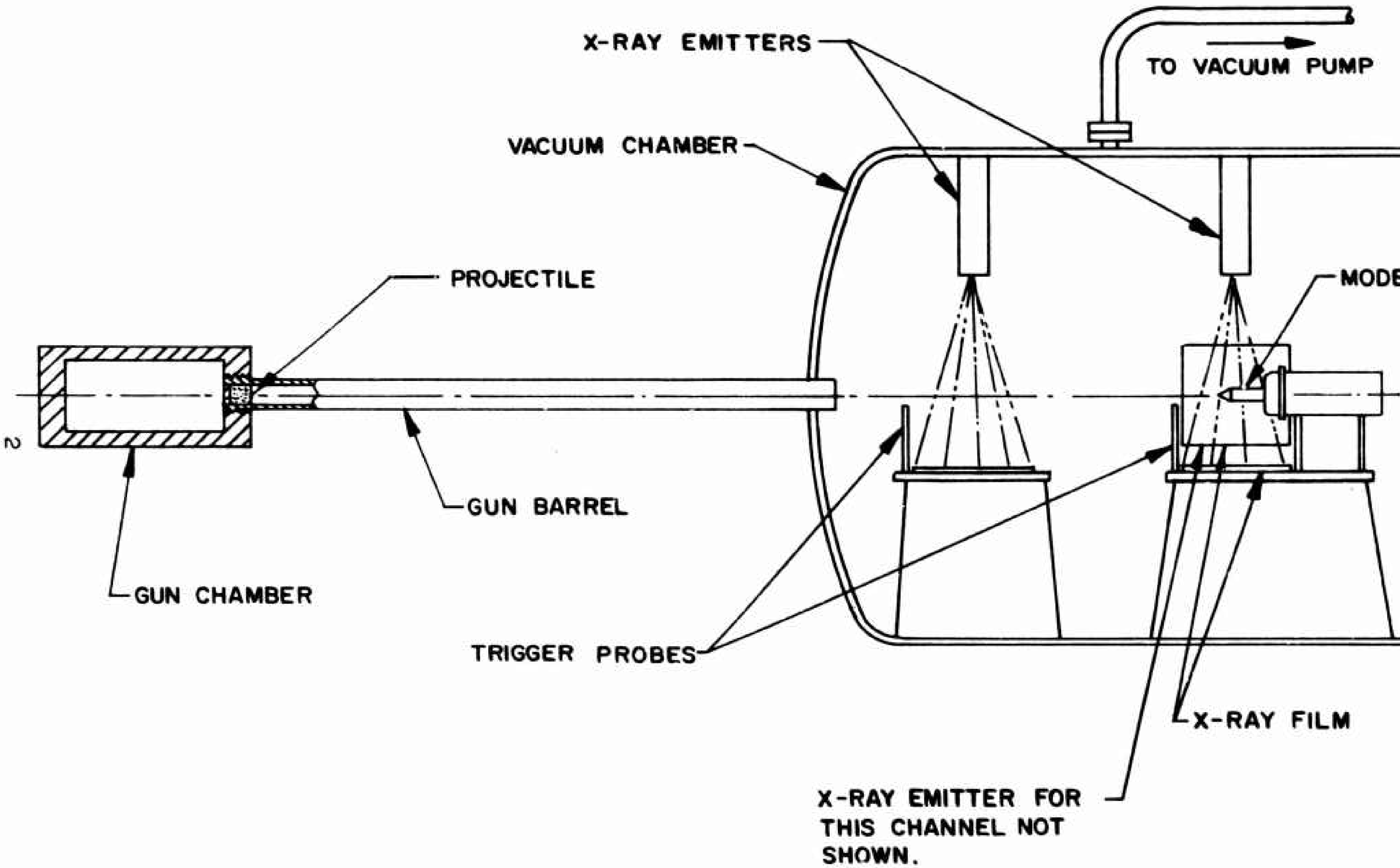


FIG. I PENETRATION TEST FACILITY.

The velocity and attitude of the impacting projectile immediately prior to impact are recorded through use of a flash X-ray system. One X-ray photograph of the projectile is taken a short distance after it leaves the gun and two more are taken orthogonally as it impacts the instrumented model. The time between X-ray pictures is recorded by a counter for velocity determination. Triggering of the X-rays and counter is done with small glass rods painted with conductive material which form part of an electrical circuit. These rods are broken by the sabot portion of the projectile, see figures 1 and 2.

MODELS

The models are high strength solid steel rods, 1/4 inch, 1/2 inch, 3/4 inch or 1 inch in diameter, instrumented with SR-4 electrical resistance type strain gages. Oscilloscopes equipped with cameras are used for recording. Figure 2 is a schematic diagram of the model assembly, showing also the projectile. The model is housed inside a steel tube to prevent any effect of the gun muzzle blast on the strain gages or wiring. Each shot destroys the entire model assembly.

IMPACTING PROJECTILE

The impacting projectile is a concrete mortar or plaster of paris cylinder 3.5 inches in diameter which is contained until after impact within a phenolic sabot. A shear disk on the back of the sabot holds the projectile in place while the gun chamber is charged with air. In the first tests, (shot series 1 and 2) the strength of the shear disk determined the projectile release pressure. This pressure varied enough to give an undesirably large projectile velocity spread. The condition was corrected by placing nichrome heater wire in a groove in the sabot shear disk. After the gun chamber is loaded with air to the desired pressure, the nichrome wire is heated to burn the shear disk until it releases.

TARGET PREPARATION

The concrete mortar and plaster of paris used are specified in Appendices A, B, and C. After curing, the concrete and plaster of paris were dried in a ventilated oven at 120°F until it was certain that the weight loss had stopped. This was done to produce uniform specimens, and to slow further curing of the concrete. Test specimens for determining physical properties were poured from all of the batches mixed.

Sound speed measurements were made to determine the test time available during the shots (see Appendices A and B). This time is from impact until the first stress wave reaches the back

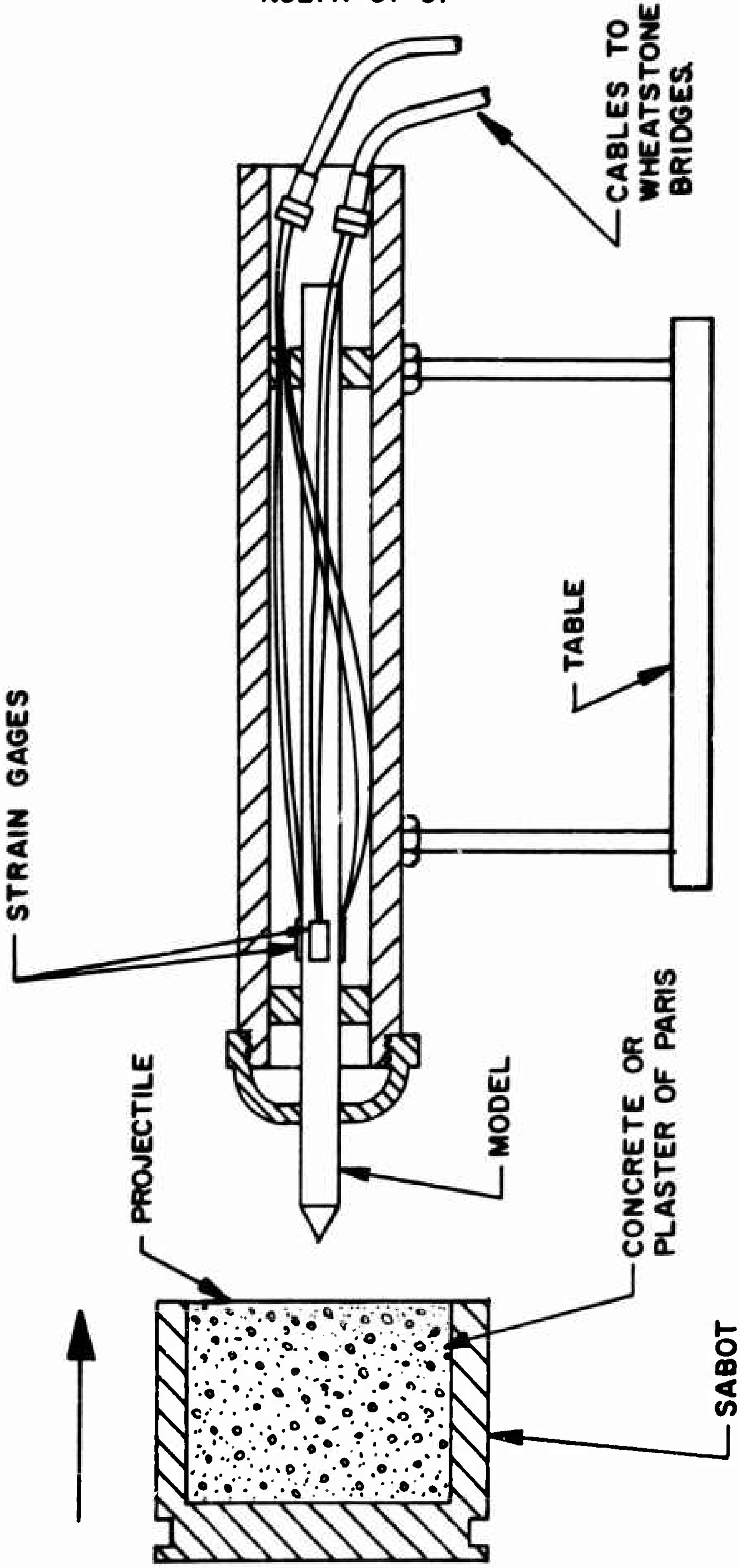


FIG. 2 MODEL ASSEMBLY

surface or outer edge of the target material, reflects, and returns to the missile model. During this time the target responds as an infinite body. The sound speeds were measured by timing the passage of a stress wave through a large diameter, right circular cylinder of target material. The stress wave was generated by an impact in the center of one end of the cylinder, and was detected at the opposite end by use of a piezoelectric crystal.

It is known that there is a strain rate effect on the ultimate strength of concrete. Reference 1 indicates that the ratio of dynamic to static strength of concrete is as much as 1.8 at dynamic strain rates up to 10 in/in/sec. This rate is one or two orders of magnitude below the strain rate reached in the impact tests in this program.

METHOD OF DATA REDUCTION

It has been found (ref. 2 through 5) that the Poncelet equation describes penetration during subterranean travel in dense media with fair accuracy. This equation may be written

$$F = (a + bv^2)g\ i\ A$$

where

F = force resisting penetration
a,b = functions of the penetration medium
v = instantaneous velocity of the vehicle
g = acceleration of gravity
i = a vehicle shape factor
A = cross-sectional area of the vehicle.

However, this equation applies to the travel of the missile after entry. During the initial entry phase, the force resisting penetration may be thought of as consisting of $\rho\frac{v_o^2}{2}$ forces (where ρ is the density of the target material and v_o is the initial velocity) which occur because of unsteady virtual mass effects as well as the steady viscous effects; secondly, an impulsive ($\rho c v_o$) force (where c is the appropriate acoustic speed) which occurs because of the compressibility of the medium: and thirdly, a force resulting from the strength of the medium. This entry force may be expressed in dimensionless form,

$$\frac{F}{\rho \frac{v_o^2}{2} A} = C_D = C_D\left(\frac{v_o}{c}, \frac{\sigma}{\rho \frac{v_o^2}{2}}, \theta, \text{geometry}\right)$$

where σ is a measure of the target strength, for example, the dynamic yield strength of the target, θ is the entry angle, and the other terms are as defined above. It is to be noted in the case of hydrodynamic impact, for example in water, the strength factor would be negligible and C_D would only be a function of velocity, entry angle, and geometry.

The force, F, on the nose of the missile was calculated from the recorded strain on the body of the missile model using the relationship

$$F = E\epsilon A$$

where

E = modulus of elasticity of missile model
ϵ = measured strain
A = cross-sectional area of missile model.

The above relationship assumes only that the stress wave in the missile model is plane. The model is long enough that no stress reflections from the back of the model reach the strain gages during the test time. The steel model remains elastic.

Shot Series No. 1. The first series of shots made, shots 1 through 36, were at a nominal impact velocity of 2000 feet per second. Models of 1/2-inch and 1/4-inch diameter were impacted by concrete cylinders made with an aggregate gradation scaled to the model size. A complete description of this concrete is given in Appendix A. Strain gages cemented on the model were used to record only axial strain since the impact was normal. Electrical noise generated during the test time gave considerable difficulty in the first shots because it got into the data recording system. The data from some of these shots had to be discarded for this reason. The problem was eliminated by careful grounding of the model. Figure 3 is a reproduction of an oscilloscope trace typical of all the shot series.

Table 1 gives the data from the first test series.

Shot Series No. 2. At the conclusion of the first shot series, it was felt that the concrete used in that shot series was not fully satisfactory because of the relatively large size of some of the pieces of aggregate. The test results could perhaps be noticeably influenced if the model impacted one of the larger pieces of aggregate directly. It was therefore decided to use only fine sand as aggregate. Since curing new concrete involved some time delay, it was decided to fill in the schedule by firing some control shots using plaster of paris. It was felt that these shots would be helpful in further developing test procedures, and data analysis and reduction techniques. The reason for the choice of plaster of paris was that it is quickly and easily manufactured and cured, the properties can be well controlled, and it is similar in character to concrete.

Shots 37 through 56 were made with plaster of paris target material. The majority of these shots were with a hemispherical nose shape. Figure 4 is a plot of C_D versus nose penetration resulting from four shots in this series with hemispherical nosed models 1/4 inch, 1/2 inch, 3/4 inch and 1 inch in diameter. These shots indicate an absence of any scaling effect.

Table 2 gives the data relevant to these shots. The plaster of paris mix is described in Appendix B.

Shot Series No. 3. The third series of shots, shots 57-77, were at a nominal impact velocity of 1900 feet per second. Models of 1/4-inch, 1/2-inch and 3/4-inch diameter with five different nose shapes were impacted by concrete cylinders having only fine sand aggregate.

Table 3 gives the data from this third test series. A description of the concrete is given in Appendix C.

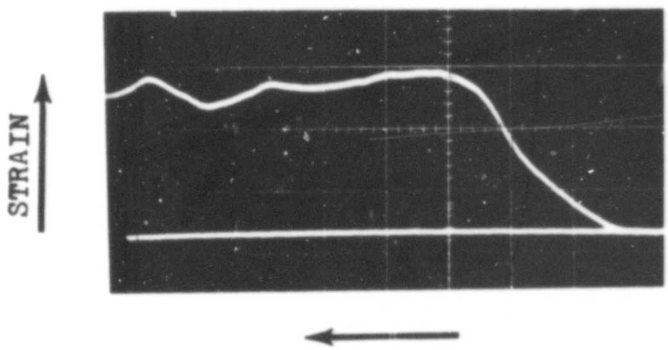


Fig. 3 Typical Oscilloscope Record of Impact (Shot No. 60)

Table 1. Shot Series No. 1
(See Appendix A for target material)

Nose shape	Model dia. (inches)	$C_{D_{max}}$	Velocity (ft/sec)	Shot No.
hemispherical	1/4	1.87	1960	16
hemispherical	1/4	2.91 (?)	1680	34
hemispherical	1/2	1.93	2000	19
hemispherical	1/2	1.58	2000	20
hemispherical	1/2	1.76	1680	27
hemispherical	1/2	1.80	1745	31
90° included angle cone	1/4	2.41	1540	36
90° included angle cone	1/2	1.65	2000	9
90° included angle cone	1/2	1.79	2100	13
90° included angle cone	1/2	2.11	1990	21
90° included angle cone	1/2	2.63	1700	28
90° included angle cone	1/2	2.38	1730	30
60° included angle cone	1/4	1.51	2020	14
60° included angle cone	1/2	1.65	1900	7
60° included angle cone	1/2	1.50	2040	22
60° included angle cone	1/2	1.90	1730	32
60° included angle cone	1/2	1.70	1800	33

Table 2. Shot Series No. 2
(See Appendix B for target material)

Nose shape	Model dia. (inches)	$C_{D_{max}}$	Velocity (ft/sec)	Shot No.
hemispherical	1/4	1.08	1820	49
hemispherical	1/4	.99	2020	52
hemispherical	1/2	1.06	1830	48
hemispherical	1/2	1.21	1810	54
hemispherical	1/2	1.64*	1160	56
hemispherical	3/4	1.04	1920	50
hemispherical	3/4	1.12	1940	53
hemispherical	1	1.06	2090	55
60° included angle cone	1/4	.70	1980	41
60° included angle cone	1/2	.76	1960	39
60° included angle cone	3/4	.68	1945	40

*C_D is high for this low velocity shot, indicating the omission of a target strength term in the C_D expression.

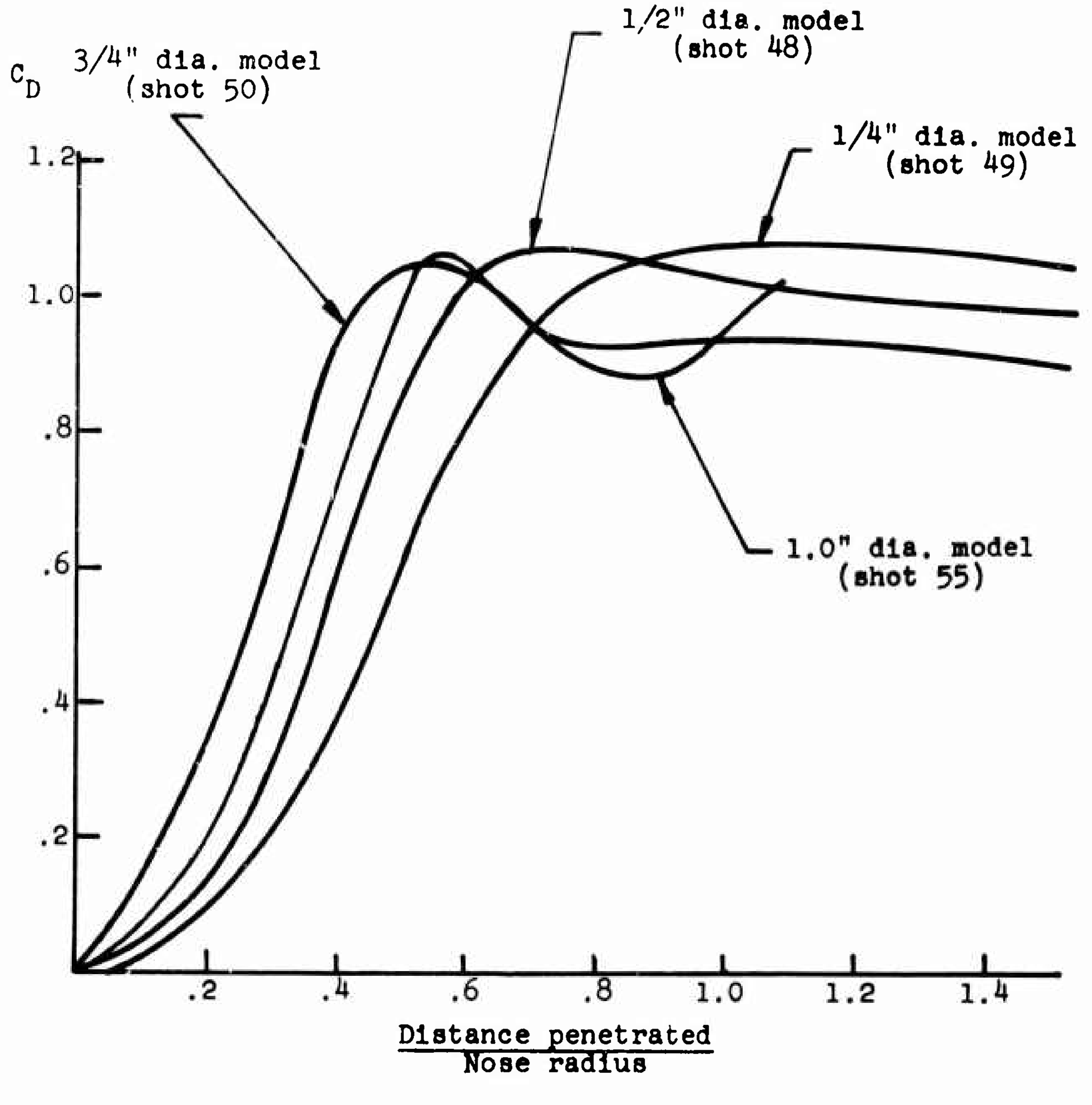
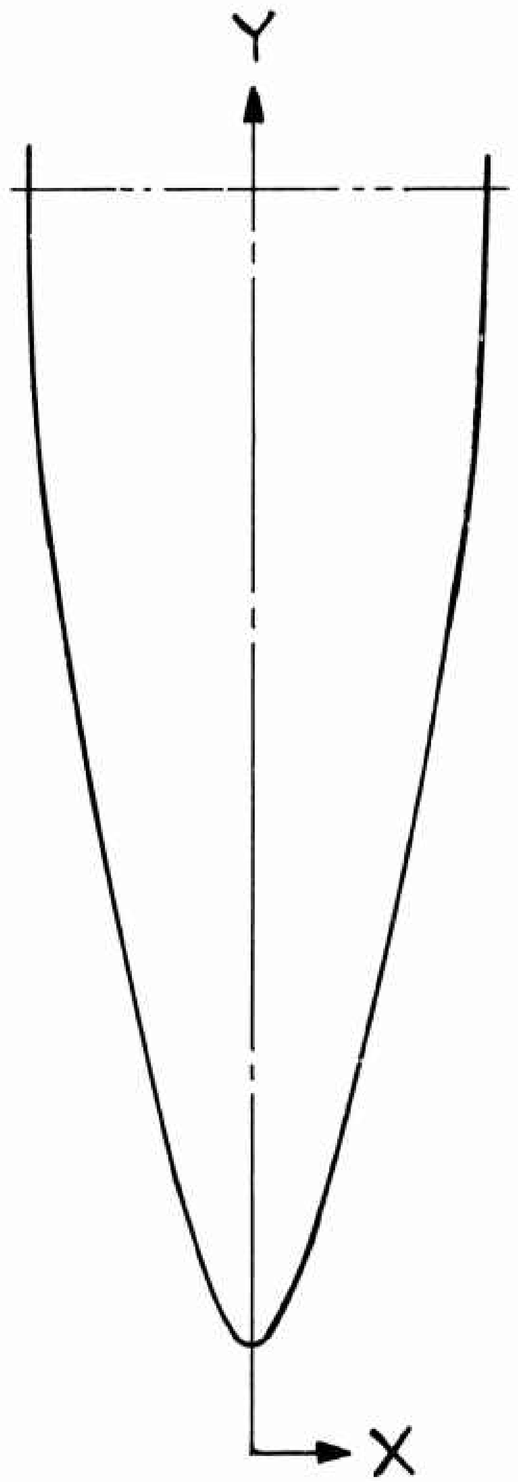


Fig. 4. Impact of Hemispherical Nosed Models into Plaster of Paris
(See Table 2 for test conditions)

Table 3. Shot Series No. 3
(See Appendix C for target material)

Nose shape	Model dia. (inches)	$C_{D_{max}}$	Velocity (ft/sec)	Shot No.
90° cone	1/4	2.29	1880	57
	1/4	1.75	1900	58
	1/2	2.00	1875	68
	3/4	2.01	1885	59
		AVG. 2.01		
60° cone	1/4	1.47	1900	64
	1/2	1.43	1870	67
	3/4	1.41	1885	60
		AVG. 1.44		
30° cone	1/4	1.03	1960	77
	1/2	1.10	1890	61
	3/4	.88	1920	62
		AVG. 1.00		
hemispherical	1/4	1.75	1900	63
	1/2	1.59	1860	66
	1/2	1.50	1885	69
	3/4	1.50	1880	65
		AVG. 1.58		
composite ogive (defined by figure 5)	1/4	1.05	1955	70
	1/2	.65	2000	71
	3/4	.71	1930	72
	3/4	.78	1935	73
		AVG. .80		



Coordinates

x	y
0	0
.036	.016
.051	.032
.062	.048
.072	.064
.164	.230
.233	.390
.288	.551
.324	.712
.375	.872
.413	1.033
.452	1.194
.491	1.354
.528	1.515
.549	1.609
.570	1.700
.609	1.861
.646	2.022
.682	2.182
.715	2.343
.789	2.504
.779	2.664
.808	2.825
.834	2.986
.860	3.146
.869	3.213
.893	3.374
.914	3.535
.935	3.695
.953	3.856
.967	4.017
.978	4.177
.985	4.338
.992	4.499
.998	4.659
1.000	4.804

Fig. 5. Composite Ogive Nose

SUMMARY AND DISCUSSION

Models of penetrating bodies with several nose shapes were used in tests to determine the forces experienced by penetration vehicles during their impact and initial penetration of concrete and plaster of paris. Impact was always normal to the model axis. The model bodies were 1/4 inch, 1/2 inch, 3/4 inch and 1 inch in diameter and had noses that were hemispherical, ogival and conical. The conical models had included angles of 30 degrees, 60 degrees and 90 degrees. These bodies, instrumented with SR-4 electrical resistance type strain gages, were impacted by concrete and plaster of paris materials at a nominal velocity of 2000 feet per second.

The data from the instrumented models have been presented as a coefficient of drag, C_D. This C_D is a function of impact velocity, target strength, target sound speed, missile geometry, entry angle, and perhaps size. Included in this report are the results of three test series, each test series being run with a different impact target material. In a given test series, the target material and velocity were reproduced as closely as possible while the model nose shape and diameter were changed. Thus, the relationship between C_D and missile geometry is directly indicated in the tabulated data for each test series. The C_D values for concrete are seen to be about 50 percent higher than those for plaster of paris; this is thought to be a result of the differences in target strengths, and sound speeds.

No scaling effect was found as can be seen from the tabulated data or from the C_D versus penetration plot in figure 4 which includes model sizes differing by a factor of four. A modification was made in the projectile release mechanism between test series 2 and 3 which improved the reproducibility of impact velocity. This modification resulted in a significant improvement in the apparent agreement of the C_D values for given nose shapes because of the dependence of C_D on impact velocity.

It is interesting to note in figures 3 and 4 that the shape of the C_D versus penetration curves for concrete and plaster of paris are different from those of water. In water the curve falls off significantly after rising to its maximum, whereas, in concrete and plaster of paris, the curve rises to a maximum and remains essentially flat during subsequent penetration. This difference is thought to be a result of the target strength.

The scope of this study involved varying only the missile geometry and size, and none of the other variables on which C_D is also dependent. It is hoped that further work can be carried out, including (1) a more conclusive test of scaling where the model size is increased by a larger factor, (2) a parametric study in which impact velocity, target sound speed are systematically varied, and (3) an investigation of the non-normal impact case.

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APPENDIX A

Concrete used for shot series 1 (shots 1-36)

Cement: Portland Cement, Type I
manufactured by Capitol Cement Co.
Martinsburg, West Virginia

Sand-Aggregate: Yellow sand with small stone. The percentage of sand-aggregate retained on sieves was as follows:

Sieve size	% aggregate retained
3/8"	none
# 4	3
# 8	12
# 20	19
# 40	33
# 60	22
# 140	9
pan	2
	100%

The concrete mixture was 1 part cement to 4 parts sand-aggregate by weight with a water to cement ratio of 0.75, by weight. A motor-driven 1.5-cubic-foot drum mixer was used for mixing the concrete. The target projectiles were molded in 3.5-inch diameter x 2.5-inch long cardboard mailing tubes and then cured in the molds in water for two weeks. After curing, the molds were removed and the concrete air-dried at 120°F.

Average density: 133 lb/ft^3

Compressive strength (static): 1400-1800 psi

Sound speed: 5000 ft/sec.

APPENDIX B

Plaster of paris used for shot series 2 (shots 37-56)

Plaster of paris: Red Top
manufactured by United States Gypsum Co.

The plaster of paris mix was 5 parts plaster of paris to 4 parts water by weight. It was mixed by hand and molded in the target projectile sabots. After it set up, it was air-dried at 120°F.

Average density: 66 lb/ft^3

Average compressive strength (static): 1400 psi

Sound speed: 8000 ft/sec.

APPENDIX C

Concrete used for shot series 3 (shots 57-77)

Cement: Type III Incor
manufactured by Lonestar Cement Corp.

Aggregate: Sand, fineness modulus 1.20, commercially available as white asphalt fines

Sieve No.	Cumulative % retained
4	0
8	0.7
16	2.3
30	6.8
50	37.8
100	72.1
200	91.6

Proportions: 1:4 cement: aggregate by weight
water/cement = 1.0 by weight

Batch characteristics:
Flow in 10 drops 115%
Slump 5.0" (avg)
Unit weight 126 lb/ft^3

The specimens were moist cured for seven days, then dried in a ventilated oven at 120°F until no further weight loss occurred.

Dry density: 115 lb/ft^3
Compressive strength (static): 2550 psi (avg).

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13. ABSTRACT

The forces felt by a projectile were measured during its initial penetration of concrete and plaster of paris. Various nose shapes were tested. The testing technique used was that of firing concrete and plaster of paris at small-scale stationary models instrumented with SR-4 electrical resistance type strain gages on the afterbody.

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